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Natural soundscapes as a disciplinary bridge in pursuit of sustainability: research themes and priorities

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ABSTRACT

Natural soundscapes, a blend of natural and human-made sounds, enhance human health by reducing stress, improving cognitive function, and increasing happiness. They foster a connection to nature and raise awareness of biodiversity loss. Soundscapes also bridge science and art; scientists study them to understand ecological dynamics, while artists use them for creative expression. The 'Ecotones: Soundscapes of Trees' research network explored the role of soundscapes in sustainability through workshops in South Korea and the United Kingdom (May–July 2022) attended by a group of 30 researchers and practitioners from a broad range of disciplines. Discussions highlighted themes like health, quietness, cultural context, and the role of digital technology in revealing inaudible soundscapes. The network emphasized the potential of soundscapes to promote environmental empathy and wellbeing and also identified knowledge gaps, particularly regarding how contextual factors influence soundscape perception and their use. Future research will benefit both from the insights gained and the questions raised, providing diverse perspectives on how to address these knowledge gaps to better understand the impact of soundscapes across disciplines.

KEY POLICY HIGHLIGHTS

- Support natural soundscape-based therapies (e.g. within forest therapy, hospital care) to improve mental and physical wellbeing through evidence-backed interventions.
- Promote sustainable, equitable acoustic technology use in eco-acoustic monitoring and sound-based environmental engagement.
- Develop culturally-sensitive, nature-connection frameworks that reflect diverse sound perceptions and listening practices, ensuring inclusivity in environmental education, therapy, and cross-cultural ecological engagement.
- Integrate deep listening and multi-sensory soundscape activities into education to enhance ecological awareness, emotional wellbeing, and sensory engagement with natural environments.
- Support interdisciplinary, outdoor arts programmes that combine music, movement, and ecological learning to foster nature connectedness and non-extractive relationships with the environment.

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1. Introduction

There has been a growing recognition of the significance of natural sound for human health and wellbeing (Buxton et al. 2021; Ratcliffe 2021), with positive effects of natural soundscapes on physical, mental, and emotional health. While there are a variety of definitions of soundscape (Table 1), it is generally perceived as the collection of sounds that makes up the auditory environment of a specific area, and at a particular time, encompassing natural and human-generated sounds, their qualities, and the way they interact within that space (Krause 2008; Farina 2014; Pijanowski 2024). Furthermore, Grinfeder et al. (2022) introduced the concepts of distal, proximal and perceptual soundscapes to reduce ambiguities in how the term is used, and to make soundscape ecology more operational. Natural sounds (e.g. birdsongs, flowing water, and ocean waves) – which Krause (2008) refers

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Table 1. Definitions of soundscapes originating from different disciplines.

Disciplinary origin	Definition of soundscape	Reference
Urban design	'The quality and type of [all] sounds and their arrangements in space and time'.	Southworth (1967, 2).
Music composition	'The relationship of [hu]man and sonic environments of every kind [. . .] any analysis of it will be based not only on physical parameters, but rather on what may be called perceptual and cognitive primitives'.	Truax (1974, 36–37).
Music composition	'The sonic environment. Technically, any portion of the sonic environment regarded as a field of study. The term may refer to actual environments, or to abstract constructions such as musical compositions and tape montages, particularly when considered as an environment'.	Schafer (1977, 274–275).
Ethnomusicology	'The distinctive settings, sounds, and significances of a musical culture'.	Shelemay (2001, xiii).
	'The multidimensional, dynamic nature of music as it moves across time and space'.	Shelemay (2001, 359).
Ecomusicology	'The study of the flow of sound in the environment'.	Titon (2012, 2).
Landscape ecology	'The collection of all biological, geophysical, and anthropogenic sounds that emanate from a landscape and which vary across space and time, reflecting important ecosystem processes and human activities'.	Pijanowski et al. (2011, 203).
Landscape ecology	'An acoustical composition that results from the voluntary or involuntary overlap of different sounds of physical or biological origin'.	Farina (2014, 3).
Landscape ecology	'The entire sonic energy produced by a landscape and is the result of the overlap of three distinct sonic sources: geophonies, biophonies, and anthrophonies'.	Farina (2014, 1).
Landscape ecology	'Part of vibroscape perceived as sound by an organism'.	Farina and Li (2021, 10).
Urban design	Acoustic environment as perceived or experienced and/or understood by a person or people, in context.	ISO (2014).
	'The collection of all biological, geophysical, and anthropogenic sounds that emanate from a landscape and which vary across space and time, reflecting important ecosystem processes and human activities'.	

to as biophony and geophony (as opposed to human-generated sounds (anthrophony) – have a calming effect on the mind, helping to lower stress levels and blood pressure while promoting relaxation (Medvedev et al. 2015). Natural sounds are known to aid in cognitive restoration, improving focus, attention, and concentration by providing a restorative effect on mental fatigue (Zhang X et al. 2018), and improving the conditions for sleep. Natural soundscapes facilitate a sense of happiness, serenity, social interaction, and awe, contributing to overall wellbeing (Liu and Kang 2016).

It has also been suggested that exposure to natural sounds increases an individual's feelings of connectedness to the natural world, which is associated with psychological and social benefits. Indeed, the absence of natural sound has been demonstrated to raise awareness of biodiversity loss (Krause and Farina 2016). This recognition has also raised awareness of the importance of preserving natural environments and integrating natural sound into the built environment, such as healthcare settings (Mu et al. 2023), and to mitigate the negative effects of noise pollution in urban environments (van Renterghem et al. 2020; Chen and Kang 2023).

Soundscapes have the potential to form a vital link between science and art, merging these disciplines in captivating ways. Scientists utilise soundscapes to explore and comprehend ecological dynamics, biodiversity, and environmental and human health (Krause and Farina 2016). Through analysing the composition and traits of soundscapes, it is possible to understand species behaviour, distribution, and the impact of anthropogenic activities. By contrast, artists employ soundscapes as a means of creative expression and environmental advocacy. Natural sounds infuse compositions, installations, and films, while concerns about the environment provide content for songs, all of which evoke emotions, raise awareness, and convey messages of conservation (Smalley et al. 2022; Braun Janzen et al. 2023; Gough 2024). Soundscapes offer aesthetic appreciation akin to visual art, enabling artists and scientists to delve into the textures, harmonies, and rhythms within these auditory landscapes. By merging scientific inquiry with artistic interpretation, soundscapes provide a profound and immersive connection to nature, bridging the realms of science and art.

The convergence of art and science, results in a dialogue between the objective, reductive, epistemological truths of science complemented by the general subjective truths of artists who are attendant to the ontology of space, place and time. Marcuse (2007) argued for a cognitive, or intellectual art that was true unto itself, or at least capable of revealing hidden and repressed truths: 'The artistic process thus is the liberation of the object from the automatism of perception which distorts and restricts what things are and what things can be' (Marcuse 2007, 117). He goes on to argue that 'Genuine art provides an experience that helps liberate the individual from thrall to the existing society to cultivate a critical subjectivity capable of motivating transformative action to produce a better world' (Marcuse 2007, 77). Thus, by their nature, soundscapes are a phenomenon that as a resource for art and science, both separately and collectively, are potentially a powerful means to influence society towards a more sustainable future.

The present analysis is the result of a series of multi- and inter-disciplinary workshops held in the United Kingdom and South Korea that were the core

component of the 'Ecotones: Soundscapes of Trees' research network that sought to find new ways to communicate an awareness of environmental issues through the soundscapes of trees. These countries were determined by the funding source with a view to evaluating the findings and exploring their potential application to other countries (see Funding and Acknowledgements). Here, we outline the key themes and associated research questions that were the result of structured discussions between the workshop participants from a broad base of disciplines that included ecologists, sociologists, forest therapists, pedagogues, musicians and artists, providing a range of perspectives on the role of soundscapes in their work.

2. Materials and methods

Between May and July 2022, researchers and practitioners came together through a series of workshops in South Korea and the United Kingdom to discuss the role and influence of the sounds of forests in their respective disciplines (Table 2). For a full list of attendees and disciplines, see Supplemental Material 1, Table S1.

A diverse pedagogy was employed across the workshop activities that included creative, artistic, constructivist, collaborative, inquiry-based, and reflective approaches. While the difference in pedagogical approaches reflects established norms across disciplines, this diversity also facilitated different modes of learning across the network, encouraging open dialogue and accommodating different cultural practices. Outside the planned activities there was time for individual reflection and informal discussions. To mitigate and reduce language barriers, professional interpreters were employed during plenary talks, a bilingual research assistant provided in-person translation during the workshops, and Korean/English translations were provided for key texts and presentation slides. The workshops were attended by a core network of partners: five from South Korea, five from the UK. To encourage the participants to explore different research and perspectives on soundscapes, and the influence of sound across disciplines, core members of the Ecotones network were expected to attend all sessions. However, only five of the UK members, travelled to South Korea for the workshops there, in May 2022. Further attendees were invited to participate in specific workshops, facilitate workshop activities, or give guest presentations. In all, the Ecotones workshops were attended, at least in part, by over 30 participants representing academic, public, charitable and private sectors (see Supplemental Material 1 for further detail).

2.1. Data collection and synthesis

An inductive thematic analysis was undertaken based on the discussions had during deliberative reflection sessions held at the end of each workshop (Table 2). Each approximately 90-minute session followed a consistent format that combined a mixed approach to gathering reflections from all participants (core and extended network). Firstly, all attendees were invited to verbally reflect upon individual elements of the workshops, followed by a time-limited discussion aimed to capture key areas of debate or consensus, keeping in mind the Ecotones network objectives. This discussion was recorded, translated from Korean to English where required, and transcribed. Secondly, sticky notes were used to invite all participants, independently a) to express any key comments, insights or questions that could be about specific or general elements of the workshop, and b) to note any areas for development or next steps that could point towards future outputs or outcomes from the network (e.g. promising research avenues). These notes could be written in Korean or English, and participants were at liberty to record these comments anonymously. Empirical information that evidences each theme is captured in Supplemental Material 2.

In addition, all co-authors were invited to consider the extent of overlap between the different themes identified. This was achieved by scoring the strengh of the connection from themes between 1 (weak) to 10 (strong). The resulting values were averaged and entered into an adjacency matrix. The R Statistical Software (R Core Team 2024) package 'igraph' (Csárdi et al. 2024) was then used to visualise the strength of connection through the creation of a network graph based on the adjacency matrix. The network graph visualises the strength of connection

Table 2. Ecotones workshop locations, dates, and broad themes in 2022.

Location	Dates	Broad themes
1. National Center for Forest Therapy, Yeongju, South Korea	7–9 May	Growing music, human health and wellbeing, and forest health.
2. Dartington Trust, Devon, UK	18–20 July	Nature's ensemble, eco-creativity, and eco-literacy.
3. Bristol and Bath (various venues), UK	21–22 July	Tree cities and forest education.
4. Glasgow (various venues), UK	25–26 July	Urban development, sound spirit and Scotland

Additional detail can also be found in Supplemental Material, Tables S1 to Table S5.

between any two themes and scores each theme for their overall centrality to the discussion.

3. Results and discussion

This section identifies the key themes that arose from workshop debates and discussions, and the emergent research questions. The themes are wide ranging, highlighting the breadth of the network and the expertise of its members.

3.1. Soundscapes and human health and wellbeing

Workshop discussions frequently returned to the interaction between human health and wellbeing, and soundscapes. A strong theme running through them was the potential for sounds to be used in interventions such as forest therapy or forest bathing, via the concept of healing soundscapes, as well as education and learning approaches such as Forest School. These ideas were set against the backdrop of South Korea implementing their forest healing programme at over 70 centres across the country (Park et al. 2021).

Evidence suggests that biotic sounds from wildlife such as birds, animals and insects and abiotic sounds such as wind, rain, water, rustling leaves can have a positive impact on people physiologically and psychologically. In a qualitative study of peri-urban woodlands, O'Brien et al. (2014) found that in terms of pleasant sounds, people talked about birdsong but also mentioned rustling trees, crunchy leaves, peace and quiet, and trees blocking out other sounds such as traffic. Birdsong is perceived as psychologically restorative (Ratcliffe 2021), and people want to conserve those sounds particularly when they think they might offer therapeutic outcomes (Smalley et al. 2022). From a systematic review and meta-analysis, Buxton et al. (2021) outline that exposure to natural sounds can improve health outcomes such as reduced blood pressure, heart rate and cortisol levels, decrease annoyance and stress levels, and increase positive emotional states. The health and wellbeing benefits tend to be greater for those demonstrating a higher connection to nature, and similarly, the memories triggered by sounds can also influence the restorative effects of soundscapes (Smalley et al. 2022).

The evidence base connecting nature engagement with positive wellbeing underpins numerous clinical and non-clinical interventions globally, including at the National Center for Forest Therapy, Yeongju, the site of the first Ecotones workshop (May 2022). Outdoor therapies are also offered as part of Green Social Prescribing within the NHS UK's Long Term Plan (2019). In hospitals, the value of broadcast soundscapes in recovery from severe trauma has been widely assessed, with generally small but positive effects manifested through lower levels of perceived pain, reduced blood pressure, and improved sleep (Guidolin et al. 2024). Natural sounds can also help to mask anthropogenic sounds (Benfield et al. 2020). Sounds can be an indicator of a healthy or degraded environment and the United Nations Educational, Scientific and Cultural Organisation (UNESCO) has formed a sound charter to promote awareness of sounds in relation to environmental health (Paine 2018).

Key research questions

(1) Can incorporating a focus on natural soundscapes into existing therapeutic interventions improve wellbeing and create empathy with nature?
(2) What natural or nature-derived (e.g. synthetic) sounds enhance the wellbeing effects of nature-based interventions?
(3) Could a universal framework be established for testing physiological measures and feedback by comparing national methodologies and approaches?

3.2. The capacity of technology to reveal the inaudible

The group participated in a collective listening walk using a variety of audio technology to reveal sounds that are inaudible to humans (e.g. underwater, inside trees, bat detecting) (Table S1). Methods included recording, playback and amplification of natural sounds. There was a consensus that technology allowed participants to see and hear things that are otherwise invisible or unheard. This encourages a more intimate relationship, alongside a sense of fascination that stimulated the imagination. There were also reflections about the equipment and its potential use in pedagogic settings (see also Section 3.9).

The sonification of plant data was shared at Collins Goto Studio, Glasgow, with their work *Plein Air* (Collins and Goto 2019), and via documentation of Kathy Hinde's installation ' … of which we are part … ' (Hinde 2022). Both installations utilise sensor data from trees and plants including rates of transpiration, photosynthesis and water uptake as the basis for generative compositions. Both works are focused on engaging the listener towards a more imaginative, creative and empathetic relationship with the hidden workings and 'aliveness' of the plant or tree mediated through technology and creative intervention while also gathering data. These performative artworks build upon a history of experimental work with plants, sensors and sound as discussed by Castro (2020). Artists and musicians using

recorded soundscapes as a basis for extended creative practice in experimental music and sound art is an area of current expansion (Barclay 2013; Bianchi and Manzo 2016), the outcome and method being more akin to a generative composition (Sexton 2007), or an open score activated and changed by the variations from data input (Worrall 2019).

It was further recognised that the detection of changes in soundscapes is applicable in scientific contexts such as gaining insight into large data sets and for automated plant watering and other agricultural systems (Del Stabile et al. 2022). Such intimate observations of sound recorded via a range of increasingly sophisticated technology offers potential for connecting people to their surroundings (Moscoso et al. 2018, see also Section 3.5) and to monitor human impacts upon ecosystems both sonically and ecologically. Indeed, eco- and bio-acoustics have rapidly emerged as methods for remotely monitoring ecosystem health (Laiolo 2010; Farina and Gage 2017; Sueur et al. 2019), often in environments not usually audible to the human ear (e.g. freshwater) without technological intervention.

Key research questions

(4) To what extent does revealing natural soundscapes otherwise inaudible to the human ear increase environmental empathy?
(5) How can creative practice and experimental music connect people with the inaudible soundscapes of ecosystems?
(6) What is the potential for soundcapes to reflect the health of whole ecosystems?

3.3. The possible drawbacks of digital technology and sustainability

It was suggested that technology may be used to play back recorded natural soundscapes in instances where the outdoors is not easily accessed (e.g. Helsinki airport; Campos 2020), and to act as a 'stepping stone' between artificial and natural (or perceived natural) worlds. Other therapeutic applications are the playback of natural soundscapes where people are hospitalised or have restricted mobility (e.g. due to disability), and whilst receiving potentially traumatic medical treatments to encourage relaxation and relieve stress. However, concerns were raised about the interaction between nature and technology possibly altering the connection with nature, even revealing a sense of longing, or increasing stress when hearing natural sounds out of context (Batson 2020). There were also concerns that while technology could bring people closer to nature, it also draws from it in its construction, raising questions about the origins of raw materials, their carbon footprint, and their disposal.

The added value of acoustic approaches for understanding ecological impact (i.e. eco- or bio-acoustics) is that they are non-invasive and less environmentally damaging (Linke et al. 2018; Farina et al. 2022) than conventional biological sampling techniques (Drinkwater et al. 2019). Yet, while there may be negligible direct impacts because of the acoustic device used, their components and construction are not without impact. For example, rare earth elements (REE) are found throughout electronics equipment (Balaram 2019) including batteries, LED screens and solar panels, often used in soundscape recording or monitoring.

Demand for REE is increasing rapidly (Goodenough et al. 2018) and environmental and social impacts occur during acquisition, transportation, manufacture and disposal (Koltun and Tharumarajah 2014), including carbon emissions, human health risks and contaminated waste (Dang et al. 2021). Access to electronic devices may also be socioeconomically inequitable. However, increasing energy usage efficiency, decreasing cost, and integrating life-cycle thinking can help mitigate such impacts (Hill et al. 2018). For example, an increasing number of electronic devices are deployed for the use of passive acoustic monitoring (PAM) that rely on battery power, which while independently efficient in their energy use are a collective energy drain, source of significant carbon emissions in their manufacture, and risk chemical pollution in their disposal (Gabrielli et al. 2024). For example, the maximum footprint (cut-off) of a lithium-ion battery is 8.1 kg CO_2-eq. per kg (Sadhukhan and Christensen 2021), which equates to approximately 122 g CO_2-eq per 1.5 v AA lithium battery.

Key research questions

(7) How are natural soundscapes perceived when listened to out of context?
(8) How does the medium of technology interface with how people perceive the natural environment?
(9) What are the social and environmental implications of using technology to monitor and connect people with nature?

3.4. Sound complexity and subjectivity

The subjective nature of listening, and the different meanings sound can hold for different people became apparent during the workshops. A complex soundscape, for example, may be composed of entirely natural sounds, or a combination of natural sounds and anthropogenic noise (Krause 2008; Grinfeder et al. 2022), or natural sounds in a non-natural, i.e. urban, context that can shift the way in which sound is perceived (Davies et al. 2013; Hong and Jeon 2015). Soundscapes comprised of both natural

and cultural sounds can have mixed effects upon human comfort (Kang 2017), with different components of natural soundscapes eliciting different emotional responses (Wang et al. 2022).

A related concept is wildness: flora and fauna living or growing independently of people, in natural conditions and with natural characteristics. While sound-based metrics are increasingly being used to indicate biodiversity intactness in the fields of bio- and eco-acoustics (Sueur et al. 2014), there is no guarantee that complex natural soundscapes will result in human comfort. For example, night winds in the mountains can cause fear (Liu and Kang 2016); Björk (1985) found people rated the sounds of lapwings and gulls as less pleasant than other birdsong such as chaffinches; Hume and Ahtamad (2013) found people thought waves and birdsong pleasant but not the sound of foxes; and van Renterghem et al. (2020) identified low preference for the sounds of bees in playback devices secreted in urban parks (see also Section 3.3). This has implications for places with intact and wild landscapes where potential harmful wildlife exists, or where cultural stigmas persist. In such geographies, managed cultural landscapes, and therefore soundscapes, may be more comfortable for people but conflict with modern conservation paradigms such as nature recovery and rewilding (Perino et al. 2019).

Key research questions

(10) What is the relationship between intact, wild soundscapes and people, and how does this vary geographically?

(11) What combinations of natural sound promotes human health and wellbeing, and comfort?

(12) If elements of natural, or wild, soundscapes do not promote human comfort, what are the implications for biodiversity conservation in socio-ecological systems?

3.5. Nature connectedness and economic growth

A creative outcome of the workshops was The Ecotones Ensemble (see Table S2) which sought to consider whether collective activities that focused on listening and creating music in forests and other outdoor environments could improve environmental empathy and nature connectedness. These activities were trialled in outdoor settings at Yeongju National Center for Forest Therapy, South Korea, and in fields bordered by woodland on the Dartington Hall Estate, UK. For example, in two groups we co-created a musical composition using natural elements (including sticks, leaves and stones) and voice.

Multiple studies have suggested that time spent in green space can improve people's emotional wellbeing and physical health (Kaplan and Berman 2010; Hartig et al. 2014; see 3.1). Moreover, the effect of the positive benefits of time spent in green space for health and wellbeing, as well as building confidence and sociability, can enable people to feel more connected with the natural world (Zelenski and Nisbet 2014; Pritchard et al. 2020). Potential methods, such as the Connectedness to Nature Scale (CNS) (Mayer and McPherson 2004), help to evidence change in people's connectedness with nature as a result of activities involving listening or creating music.

A key aspect that emerged from discussions was the potential value of listening as an activity which acts to raise awareness of biodiversity loss and indications of shifting baseline syndrome (Pijanowski et al. 2011; Krause 2015; Barclay 2019; Haskell 2022). While comparing acoustic richness or complexity over time could evidence changes in biodiversity (Krause and Farina 2016; Morrison et al. 2021), sound may also be a powerful way of engaging society with conversations about the value of biodiversity through sensory perception.

How sound can invoke memory, sense of place, of self, and relation with nature is mediated by and built upon acts of listening. In literary and cultural studies, extensive research has been conducted into the philosophical and aesthetic significance of the 'impression' as outlined by Marcel Proust in his novel *A La Recherche Du Temps Perdu* (1913–1927). Here, an aged Proust unlocks an involuntary and seemingly forgotten memory through the distinctive taste of a madeleine cake dipped in tea. Throughout the ensuing narrative, he re-experiences memories brought back to consciousness as though 'fresh', through sensory triggers, including scent, touch, and sound. Research in psychology has validated the importance of these senses in evoking memory (e.g. Smith 2013; Herz 2016). A discussion point raised by the Ecotones network was what listening might trigger, in terms of memories of childhood listening and reconnection with a past self, and those who might have had a more vivid and active connection with nature.

Locational context was also considered, given the high-income economies of both the UK and South Korea, the latter having had recent and rapid industrialisation and urbanisation. Consequently, many people who participate in the Forest Therapy Programme are residents of and workers within Seoul (Kim et al. 2015), often accessing it through placements organised by their companies. At the Yeongju workshop, discussions took place about the parallels and differences between societies and cultures, and what can be learnt through comparison. British society, urbanised and industrialised in the 19th century, experienced its own distinctive nature-wellbeing movement, characterised by social and

cultural movements which aimed to reconnect people with nature as a beneficent agent capable of imparting vital moral lessons not available through 'civilised' culture (Hickman 2013). Wordsworth (1798) exhorted learners to quit their books, as '*tis a dull and endless strife/Come hear the woodland linnet,/ How sweet his music! on my life,/There's more of wisdom in it*'. Similarly, the nature poet John Clare (1908) devoted extensive attention to closely-observed nature, including a kind of linguistic notation '*Wew wew wew wew chur chur chur chur/Woo it woo it could this be her*'. Clare's later life was marked by a mental health crisis and a sense of disconnection from loved places, brought about by land enclosure and displacement of rural poverty, and his late writing and biography has often been read in environmental literary studies (ecocriticism) as a cautionary tale about loss of relation with profoundly known local places and creatures. Thomas Hardy similarly expressed his concern over a disconnection from nature due to rapid economic growth in his poem 'The Darkling Thrush' (Hardy 1900).

Key research questions

(13) Does the creation of music in nature, with nature, promote nature connectedness?

(14) How transferable are lessons learned from the effect of economic growth on nature connection between the United Kingdom and South Korea?

(15) How important are soundscapes to a sense of self and place attachment?

3.6. Cultural connections and indigenous knowledge

Specific qualities of historic British nature-culture and its intersection with urbanisation and industrialisation, and human health and wellbeing opened up an interesting comparison with the distinctive cultural inheritance of South Korean Forest Therapy. This included exploration of how Shamanic traditions may be present as a 'residual discourse' (Williams 1977) in modern South Korean nature appreciation, and how songs, storytelling and poetry might reflect and help rebuild both intercultural and South Korea-specific practices of nature attunement and listening.

Whether sounds are derived from humans or from our natural surroundings, their effect on people varies according to environmental and cultural differences, and personal sensitivity (see also Section 3.4). The different meanings attached to sounds in nature are often specific to cultural background and experience. For example, in Korean culture, bamboo holds profound symbolic significance, embodying values such as integrity, resilience, and purity (Grame 1962). This symbolic association with the plant extends to traditional music, where bamboo is used as the main material for various instruments, hence imbuing the instruments and their sounds with the same anthropomorphic qualities. In the UK by comparison, such similar properties are often ascribed to native trees species such as oak and ash (e.g. O'Brien et al. 2024). Indeed, there has been a global growth in demand for ethically sourced, sustainable, and natural products i.e. 'green' wood, etc (PWC 2023).

Another example where indigenous knowledge can enhance the persuasiveness of comparative research is in the project, Exploring and Exchanging Communications about Trees (https://treesofhopeinzimbabwe.org/research/), 2023–25, a partnership between Trees of Hope Community Interest Company UK, a rural community in Domboshava and its village primary school, the University of Zimbabwe, Rhodes University, and Bath Spa University (Bayley et al. 2025). The focus here was not on soundscapes per se but rather an integrated approach to forest restoration, drawing on the Shona concept, *chinyakare*, as a way of living: returning trees to rural Zimbabwe starts to bring back birds, insects and other wildlife, as well as their physical and medicinal attributes recognised by the elders, and celebratory songs, dances and stories, about trees, nature, land and water); and *chimanjemanje*, new ways of learning and doing. Cross-cultural comparisons can, however, be more problematic when soundscapes are associated with severe deforestation, as Green (2025) articulates in detail in the Ajusco-Chichinautzin region south of Mexico City.

The demand for and use of natural products extends to musical instruments, and often specific kinds of woods for specific purposes, each with ethical and environmental implications. Hyelim Kim reported on the link between her instrument, the *taegŭm* flute, and climate change, and her understanding of how bamboo has evolved. Almost all traditional Korean musical instruments use natural materials in their manufacturing process. Renowned for its robust interior, the *ssanggol chuk* variety of bamboo is deemed ideally suited for crafting traditional flutes which feature double-sided ducts that traverse the body. Since bamboo trees (like other trees) are connected through their roots (Wohlleben 2016), once one tree is affected by environmental conditions, the whole forest is susceptible. For example, intense heatwaves or heavy rainfall can impact the growth of *ssanggol chuk* bamboo and its quality. The threat of climate change therefore has a direct link to the survival or sustainability of traditional music, because if there is a decrease in the availability of natural products for making the instrument, there will be a loss of knowledge of Korean traditional music.

As listeners, Robinson (2020) encourages us to rethink critical listening positionality and relationality, arguing for an empathic listening. He suggests ways to consider various settler, diasporic, immigrant or 'arrivant' subjects by offering 'strategies for decolonising and resurgent listening' (2020, 258). From within the Ecotones network, it was noted how it takes time (years) to listen and understand an other, a sentiment conveyed by anthropologists, artists and ethnomusicologists across a variety of contexts who illustrate and analyse ways of listening, or teaching/learning how to listen to human or non-human others (Levin 2006; Barclay 2014; Ochoa-Gautier 2014; Impey 2018; Shevock 2018; Haskell 2022). Listening (and then understanding), might bring you closer to the other (person or tree), promoting ethical regard for them (Pitt 2018).

The Ecotones workshops invited a rethinking of cultural differences. For example, scientific measurement of attitudes towards, perceptions of, and feelings about nature generally, not necessarily relating to sounds or listening, rely on psychological scales imported from the West and translated into Korean (Kim et al. 2023; Yeon et al. 2023; Aletta et al. 2024). Experiences from the Ecotones network create a strong argument for developing more culturally-nuanced scales of measurement. Such an approach might also consider religious perspectives which can shape how people value nature (Zhang D et al. 2018; Ives et al. 2024).

Aside from perception or philosophy, the physical and historical differences in nature between Korea and the UK are also responsible for cultural differences. Forests now cover 64% of the Republic of Korea (South Korea) following a period of forest transition from 1955, and a government-led reforestation policy in the 1970s (Bae et al. 2012). This compares with woodlands covering 13% of total land area in the UK. Tensions can arise when a managed cultural landscape might not be 'pure' nature nor biodiverse. South Korea is an example of post-disaster nature, where people seem to be re-learning the value of forests. This raises a question regarding nostalgia for pre-deforested Korea following decades of colonial rule. A collection of individual and blended soundscapes from both countries could be used to illustrate differences in nature and culture or serve as an outcome of these interventions.

Key research questions

(16) How can we collate or connect with a wide range of examples of indigenous communities 'listening to the land' and interacting with nature?

(17) How can stronger and more widespread connections be made between traditional music and nature, in a participatory way, and as an alternative to popularised, commercial soundscapes?

(18) How can understanding and experience of traditional music be applied to understanding cultural differences?

3.7. Perceiving quietness and deep listening

During the workshops multiple activities involved elements of 'tuning in' to the surroundings, whether in the practice of 'body weather', the Ecotones Ensemble, tree yoga, or moving with trees.[1] Such invitations to silence and stillness were seen as a gift relative to the pace of everyday life and were likened to mindfulness activities, as they allowed participants to better perceive the surrounding soundscape. The practice of tuning in is synonymous with 'deep listening', a technique in musical practice for actively listening (distinct from hearing) and being conscious of the surrounding auditory environment (Oliveros 2005). While deep listening can increase perception and understanding of a place, it may also have restorative benefits (Kalita 2020). Through this technique, music students can learn about musical expression and performance (Campbell 2005). Deep listening to natural soundscapes can also bring about a less extractive approach to music composition inspired by those soundscapes.

Further to discussions centred around deep listening were considerations about how silence was achieved and the meaning of quietness. To this end it was observed that quietness could be absolute, measured by the actual sound level, or context dependent (e.g. transitions from a centre of activity into a wooded area) and achieved through a process in time, incrementally reducing the sound level. How silence or quietness is perceived may also influence the effectiveness of mindfulness exercises. For example, restoration and calmness could be improved in the presence of natural over urban or silent soundscapes (Smalley et al. 2023), yet audio-visual interaction (e.g. Franěk and Petružálek 2024) and individual perceptions complicate this relationship.

In ecomusicology, listening to the volume (dynamic level), as well as the complexity of natural sound, there is an increased capacity to involve nature as a collaborator by 'creating sounds that live under the volume of nature' (Chase 2024). Indeed, the development of deep listening tutorials could improve eco-literacy and an awareness of background noise pollution in urban contexts, and could help to isolate natural sounds from complex soundscapes comprising both artificial and natural sounds. Thus, a more proactive listening experience, augmented by modern technologies (e.g. Section 3.2), could enrich the experience and generate an empathy with nature. Similarly, it has been suggested that the translation of sounds through movement practices (e.g. birdsong into hand gestures or the practice of Body Weather)

could also help us to attune to the soundscape and raise ecological consciousness (Candelario 2019).

Any of the above could create a new perspective or discovery about the forest, such as sounds heard through a tree inspiring fascination, or sounds of a tree demonstrating daily and seasonal rhythms in response to weather patterns. Similarly, the sound environment can be explored at different levels from micro to macro, offering a chance to think of a more-than-human approach by listening to trees, thus creating openings to engage, connect, and empathise.

Key research questions

(19) What are the best approaches or combination of approaches to 'tune in' to natural surroundings?
(20) Is there an optimum transition to quietness over time e.g. a time-domain-exposure index?
(21) What is the added restorative benefit of deep listening exercises before outdoor exercise such as forest therapy?
(22) Could the practice of deep listening enable a more equitable relationship with nature?

3.8. Sound as part of a multi-sensory landscape

A soundscape may be understood as part of the dynamic way in which people perceive the world involving a variety of senses that influence the perception of each other (Lindquist and Lange 2014). For example, pleasant food odours can influence or improve acoustic comfort (Ba et al. 2022). Therefore, the experience of natural soundscapes could be further enriched by integrating them with other sensory stimuli, such as visual perception of the natural landscape and olfactory sensations evoked by the surrounding fragrances (see also Section 3.5). Similarly, individuals may experience physical sensations, such as vibrations resonating through their bodies, or even visualize accompanying imagery triggered by specific sounds (Hubbard 2010). This phenomenon emphasizes the multi-sensory nature of sound, transforming it into a full-bodied sensory experience.

Multi-sensory sound-making processes inspired by outdoor listening could heighten a person's sensitivity and perception of a given location. For instance, engaging in the act of touching (notating) tree bark to inspire a sonic composition could foster a profound multi-sensory connection to a place (Friend 2023), in this case connecting with a particular tree or environment. Engaging multiple senses has the potential to leave an indelible mark on an individual's memory and facilitate observations of the effects of environmental factors on the human body, forging a lasting connection between the senses and place; but research is limited (Bentley et al. 2023).

Challenges emerge when attempting to replicate the authenticity of nature in anthropogenic settings (e.g. in cities or within the controlled environment of a laboratory) for restorative benefit. It is important to acknowledge that the outdoor experience encompasses environmental context, including visual and olfactory cues, and the embodied presence within natural surroundings. Although efforts can be made to recreate the sensory aspects of nature indoors (e.g. Ba et al. 2022), it remains impossible to fully capture the genuine experience of being in nature. To enhance the sensory experience of soundscapes, integrating them with stimuli based upon other human senses, such as imagery, odours and textures, could prove fruitful (Spence 2020). This amalgamation of auditory and visual sensory inputs enriches the overall perceptual experience, producing a more immersive representation of the natural environment.

Key research questions

(23) How important is sound, alongside the other human senses, in creating place attachment?
(24) How can we improve the perception and effectiveness of natural soundscapes in artificial surroundings?
(25) What information is lost if we isolate sounds from their natural, multi-sensory context?

3.9. Musical creativity, soundscapes and pedagogy

Participatory research methods challenge the idea that soundscapes are 'performed' by expert musicians. By collectively approaching music performance through nature, an entry point is accessible to all, creating an inclusive and freeing approach that (re-) sensitises us to nature and the ecosystem (Rothenberg and Ulvaeus 2009). Different experiences of nature connectedness can depend on whether we are alone or part of a collaborative activity (Moreton et al. 2019), and whether we engage one or more of the senses (see Section 3.8). The main communication method in the Ecotones workshops, was through sounds of nature, whether generated directly from the tree (fluttering leaves, creaking branches), or indirectly (e.g. from wildlife associated with the tree and its locality). Interactions with sounds were from fallen leaves or twigs on the ground, exploring textures, sustained sounds (pitched or unpitched), such as scraping, rustling, and other (stick-snapping) percussive sounds. These 'natural' materials provided a stimulus for creating 'nature scores' (see Figure 1) which were interpreted by the creator, or by somebody else. The scores might be performed individually or in a group, in succession, or as an ensemble.

Another objective of these creative activities was to generate interest and connections between traditional music and nature (see Section 3.6), for example,

Figure 1. Three nature scores (A, B, C) generated from participants using forest-found natural materials in the workshop led by Hyelim Kim at the National Center for Forest Therapy, Yeongju, May 2022.

through experiencing sounds of nature integrated sensitively and musically with vocal and instrumental sounds (e.g. from Hyelim Kim, *taegŭm* and Stevie Wishart, violin, Supplemental Material 3). As discussed in Section 3.7, experimenting with human-generated sounds being softer than nature, was an idea incorporated in all the workshops in different contexts, exploring different dynamic levels, timbres, and textures. *Listening* to nature sounds as a source of creating music helps to develop our sensitivity to nature, and in turn, our place in the ecosystem. Learning to listen to nature (green listening) could help to shape a new genre of Ecotones nature music. *Creating* sounds that live under the volume of nature allow us to create music with our environment, rather than just being inspired by it. Creativity is also a way of drawing attention to sounds, raising awareness, and understanding their meaning, both scientifically and culturally.

Workshop attendees recognized the potential of interdisciplinary and experiential learning to help young people awaken their senses and be stimulated by nature. Primary school children who make music outdoors have been found to be particularly connected to their emotions and senses and are empowered by a sense of freedom and agency (Adams and Beauchamp 2018). Attuning and interacting with natural soundscapes may afford children opportunities to cultivate deeper sensitivities to sound (Louv 2012). Smith (2021) suggests that a purpose of music education might be to encourage children (and all people) to maintain their sense of wonder in nature, to fully develop their sensory capacities, to support their psychospiritual wellbeing, and to foster soul-centric maturation.

Collaborative sound-making, score-making, or sound-inducing processes sensitises one's perception of a location and its (often variable) climatic conditions. Such engagements therefore provide an opportunity to think about the type of interaction between human and more-than-human (Rothenberg 2005, 2019; Kohn 2013). Specific outcomes of combining nature and music pedagogies (similar to Shevock's 'eco-literate music pedagogy', 2018) could be graded exercises (scales), and vocal and instrumental pieces devised for the Associated Board of the Royal Schools of Music syllabus), or a nature song created from soundscapes collected from different regions, with music composed with forest sounds.

A soundscape educational programme in connection with ecological art involves a process of consciously imagining and creating sound through contact with one's own body and nature. Through immersion, both physical and multi-sensory perception are connected to ecological art. Media art education is a further connection that combines science and technology equipment with art education, and can enact human, nature, science and technology (Koh 2019). Even from the relatively limited number of scientific disciplines represented in this article, it is clear that soundscapes are an accessible way of integrating science and arts subjects, thus bringing Arts into the teaching of Science, Technology, Engineering and Mathematics (STEM) subjects (Burnard and Colucci-Gray 2019). Ecological art education offers ways for observing nature and for building intimacy and sustained ways for communicating with nature. Like listening and creating, its goal is to actively observe the surrounding environment and to redefine the relationship between oneself and the environment (Devall and Sessions 1985), which has important ethical implications: there is a danger of being extractive if we focus on people benefitting from nature (i.e. nature as an instrument) at the expense of giving back to nature (Kimmerer 2020). Further study can help to address this balance by increasing our understanding of how the non-human world communicates with each other (Fischer and Cory 2015; Haskell 2022).

Key research questions

(26) How can collaborative sound-making, score-making, or score-reading processes in nature increase the accessibility of music?

(27) How can creative teaching practice contribute to a shift away from human-centred thinking

and towards a more ecologically-centred altruistic subjectivity?

(28) How can we implement an integrated STEAM (Science, Technology, Engineering, Arts, and Mathematics) curriculum through soundscape?

(29) In soundscape education, what is the step-by-step approach for integrated development such as individual cognitive, emotional, social, and ecological sensitivity?

4. Summary of research themes and priorities

Natural soundscapes, including from forests, cut across a wide range of epistemological domains including psychology, ecology, ethnography and health. The research themes outlined above are often closely related, with some themes more central to the discourse than others. Figure 2 represents the themes and their inter-relationships, identified by seven members of the Ecotones network.

Health and wellbeing (Section 3.1) cuts across most themes, and forms a triad with aspects of subjectivity i.e. how people perceive soundscapes (Section 3.4), and the related concept of quietness (Section 3.7). Each of these are interdependent and can be influenced by personal nature connectedness (Section 3.5), cultural (Section 3.6), environmental and multi-sensoral contexts (Section 3.8). Secondary nodes that nevertheless have strong connections to several other themes are, for example, the sustainability of technological devices (Section 3.3) that could influence people's perceptions of otherwise inaudible soundscapes (Section 3.2), but here there is a recognition that soundscapes can be experienced in the absence of technology. Musical creativity and pedagogy (Section 3.9) are strongly linked to cultural connections and indigenous knowledge and aspects that require the individual to 'tune-in' to nature such as recognising soundscapes as part of multi-sensory landscapes (Section 3.8) and quietness or the role of deep listening (Section 3.7). Each of these research themes, their context, and the key research questions are summarised in Supplemental Material 1, Table S7.

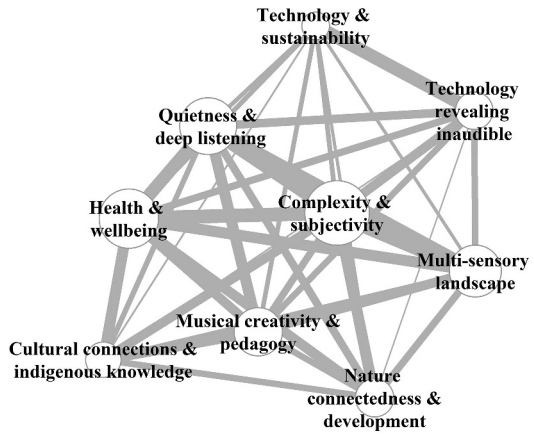

Figure 2. Themes identified during Ecotones network workshops and their inter-relationships ($n = 7$). The thickness of links indicates strength of connection, size of node reflects the number of connections across all themes.

5. Conclusion

The Ecotones research network sought to find new ways to communicate an awareness of environmental issues through the soundscapes of trees. A series of workshops took place in the UK and South Korea which included deliberative discussions that resulted in the ten research themes outlined here. The themes derived from the network are diverse and organically arose from the over-arching aim. They consider health, technology, subjectivity, nature connections, cultural connections and distinctiveness, deep listening, ecomusicology and pedagogy that reflect the range of disciplines and interests of those involved in the Ecotones events, and beyond.

5.1. Soundscapes as a bridge between disciplines

Soundscapes are considered a cross-cutting concept because they intersect with various disciplines, themes, and areas of study, linking seemingly disparate fields through the shared focus on sound, its sources, and its impacts. Within the fields of ecology and environmental science, soundscapes are studied as a reflection of biodiversity, habitat health, and the interactions between species (Turlington et al. 2024), while in urban design, soundscapes influence how spaces are designed to create environments that are acoustically comfortable (Kang 2017), and this in turn reflects research in psychology and health about the overall effect soundscapes have upon human health and wellbeing (Buxton et al. 2021). In the arts, soundscapes are used as inspiration for creative outputs, exploring the aesthetic dimensions of sound (Barclay 2019).

As a bridge between disciplines, soundscapes serve to connect people with natural systems. Natural soundscapes, such as forests, are altered by human activities such as deforestation, urbanisation and climate change (Krause and Farina 2016; Green 2025), but can also reflect cultural vibrancy or issues like noise pollution that affect public health (van Renterghem et al. 2020). They may also provide a link across both space and time being potentially valuable to track episodic noise pollution (Benfield et al. 2020), but also long-term effects of climate change and social phenomena such as shifting baseline syndrome (Morrison et al. 2021). Being an artefact of a place and time, soundscapes can be

a powerful tool in teaching about interconnected social and ecological systems (Tojeiro-Pérez and Gillanders 2024). For example, how non-human species interact with each other and with humans. Collectively, and combined with other senses, soundscapes can contribute to the identity of a place and attachment to it (Bentley et al. 2023). Furthermore, the study of soundscapes is being rapidly augmented by technological advancements, including acoustic monitoring (e.g. Sueur et al. 2014), artificial soundscapes (van Renterghem et al. 2020), and expanding the audible range through increasingly sophisticated and cost-effective recording equipment (e.g. Linke et al. 2018).

Critically, engaging in the practice of listening to sounds from nature (e.g. deep listening), crucially different from hearing, appears to develop our sensitivity to nature and heighten ecological consciousness and empathy (Barclay 2019; Candelario 2019; Regino 2023). Further, there may be added restorative benefits for health and wellbeing if listening is coupled with expressing thoughts and feelings in a creative manner for both adults and young people (O'Brien 2018; Koh 2019).

Within and between different cultures, however, the relative benefits derived from soundscape-oriented activities are likely to vary greatly (see 3.4). For example, cultural sensibilities surrounding nature are quite different in South Korea and the UK, and would be different again in many other countries. Thus, further research is required to evaluate the effectiveness of natural soundscapes for wellbeing that explores a range of interventions to identify aspects that are culturally unique and others that might be cross-cultural. Building on the content of the Ecotones workshops, further interventions would develop these processes and create new ones to activate the general public to sensitise their listening to the environment(s) around them. Comparing soundscape research in other climates and regions, e.g. urban vs. rural areas, and in developing countries, would deepen the significance and value of cross-cultural comparisons and provide an assessment of their applicability.

5.2. Limitations and constraints of the Ecotones research network

It is important to acknowledge that while there was significant disciplinary breadth across the core and extended Ecotones network (see Supplemental Material), it was by no means exhaustive. Consequently, the themes and research questions posed here are not without cognitive bias toward the disciplinary perspectives of the people involved. Similarly, while the empirical evidence has served to shape the research themes presented, and each has been complemented with secondary evidence, it is possible that in the attempt to integrate diverse disciplinary perspectives, some issues or concepts may be oversimplified. Nevertheless, attendance by all the core network members to the workshop sessions, with the exception of a Covid-19 outbreak in Glasgow, aligns with good practice for interdisciplinary research (e.g. Kelly et al. 2019).

Note

1. Ecotones participants, led by Victoria Hunter, took part in 'Drawing and Dancing with Trees' during a symposium at Bath Spa University in July 2023, organised by Amanda Bayley.

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Author contributions

Conceptualisation: IT, AB; Methodology: IT, AB; Formal analysis: IT, AB; Investigation: All authors; Writing – Original Draft: IT, AB, TC, JK, KH, HK, LoB, MR, WS, SW; Writing – Review & Editing: All authors; Project administration: AB; Funding acquisition: AB, IT, WS, JK.

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